

Impact of COVID-19 Lockdown on Air Pollutant Emissions in Port Regions. Scoping Review

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SUMMARY

Background: This scoping review, a comprehensive effort to map and synthesize evidence, sheds light on the impacts of the COVID-19 lockdown on air pollutant emissions in port regions.

Methods: It was conducted based on the Joanna Briggs Institute Manual and the PRISMA-ScR recommendations. An extensive literature search was undertaken to identify any scientific study or report comparing greenhouse gas emissions before and after the COVID-19 pandemic in maritime port regions.

Results: Nine observational studies conducted in ports of five countries were identified, 75% using the Automatic Identification System (AIS) as a measurement system for pollutant emissions. When comparing the same period before and after the pandemic lockdown, the results of seven studies identified a reduction of up to 63% in the emission of CO₂, NO₂, CO, HC, NO_x, SO_x, HC, PM_{2.5}, and PM₁₀, and an increase of 37% in O₃. Additionally, two studies reported increased pollutant emissions, explained by ship congestion in ports.

Conclusion: These findings indicate an important reduction in pollutant and particulate matter emissions during the port activity restrictions imposed by the COVID-19 pandemic worldwide compared to the same period in 2019. This reduction was mainly attributed to the reduced activity of vessels and vehicle circulation. These findings can provide valid scientific evidence to support the air pollution control policies in coastal cities and assist in ensuring sustainable practices, environmental regulations, and monitoring for mitigating air pollution in port regions.

Keywords: Port activities; Atmospheric pollutants; COVID-19; Scoping review.

INTRODUCTION

Maritime transport, a cornerstone of global trade and development for almost 70 years, plays an indispensable role in the world economy. It facilitates the movement of approximately 10 billion tons of cargo, passengers, and crew annually, as well as more than 80% of the world's transported goods. However, maritime transport poses critical environmental challenges, especially with air

pollutants and greenhouse gas emissions [1,2]. As stated by statistics from the United Nations Conference on Trade and Development (UNCTAD), there were approximately 105,500 ships in the global maritime sector at the beginning of 2023 compared to 92,295 in 2019. The majority rely on petroleum-derived fuels such as diesel and heavy fuel oil, which release large atmospheric pollutants [3,4]. According to the International Maritime Organization (IMO), shipping emitted approximately 1.056 billion tonnes of carbon

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dioxide (CO₂) in 2018, representing approximately 2.89% of global greenhouse gas emissions. It is estimated that emissions from maritime transport will double by 2050 [5].

Associated with maritime activity and due to the great demand for the transport of goods, the regions surrounding seaports also concentrate high emissions of atmospheric pollutants. The concentration of ships, cargo handling equipment, local traffic with excess trucks, and other industrial activities in port areas worsens air pollution. It represents a higher risk of environmental damage and directly harms human health, including the higher prevalence of respiratory and cardiovascular diseases and reduced quality of life for local communities [6,7,8].

Since the start of the COVID-19 (Coronavirus disease 2019) pandemic in 2020, several health restrictions have been imposed worldwide to mitigate the spread of the virus. This scenario has led to an unprecedented global hiatus in several sectors, including the paralysis of economic activities and reduced human mobility [6,9]. One notable area of change has been the alteration of air pollutant emissions in port regions. During the lockdown, maritime transport activities were significantly reduced, and many industries located in or near port regions were closed or started to operate at reduced capacity, thus restricting the movement of cargo vehicles and human activities. Despite the emergency, such changes have provided a rare opportunity to identify and better understand the drivers of global environmental disruption, including the impact on air pollution in port regions [6,9].

The growing global interest related to changes in air quality has led to the significant production of scientific studies on port regions around the world to compare the emission of air pollutants before and after the COVID-19 lockdown. Therefore, it is required to investigate the results derived from this evidence to understand the mechanism of pollution sources and their relationship with the health of the population and the environment to support the implementation of preventive and sustainable measures to promote cleaner technologies and improve environmental regulations in port regions. Therefore, this scoping review aimed to map and synthesise results from studies that evaluated the impacts of restrictions imposed by the COVID-19 pandemic on maritime port activities regarding atmospheric emissions.

METHODS

This scoping review was planned and conducted based on the recommendations of the Joanna Briggs Institute Manual for scoping reviews [10]. The review report adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses - extension for scoping reviews (PRISMA-ScR) guidelines [11]. The review protocol was registered in the Open Science

Framework (OSF) platform (available at <https://osf.io/cknhv/>) [12].

The research question was structured using the PCC acronym as follows:

- P (population): studies evaluating the environmental and/or health impacts of the COVID-19 pandemic on the port population, including port workers (permanent or temporary) and the population residing in port regions and surroundings.
- C (concept): analyses of the impact of COVID-19 pandemic-related restrictions on port activities and their environmental effects on atmospheric pollutant emissions. Approaches for measuring atmospheric pollutant emissions before and after the COVID-19 pandemic.
- C (context): seaport regions and surrounding areas, any country.

Eligibility criteria

We planned to include any primary (analytical or descriptive observational studies) or secondary study design, such as narrative or systematic reviews, that assessed the atmospheric pollutant emissions in seaport regions and surrounding areas before and after the COVID-19 pandemic. Full publications or abstracts presented at conferences and events were considered for inclusion.

Sources of information

A comprehensive search was conducted through structured search strategies for the following databases on November 12, 2023: Medical Literature Analysis and Retrieval System Online (MEDLINE, via PubMed), EMBASE (via Elsevier), Cochrane Library (via Wiley), Biblioteca Virtual em Saúde (BVS), Epistemonikos, Health Systems Evidence, SCOPUS, and WHO-COVID.

We also searched the following grey literature databases and preprint repositories: Data Archiving and Networked Services (DANS) and Open Science Preprints.

Additional unstructured searches were carried out on the following websites:

- International Maritime Organization (<https://www.imo.org/en/OurWork/IIIS/Pages/Port%20State%20Control.aspx>)
- World Ports COVID-19 Information Portal (<https://sustainableworldports.org/world-ports-covid19-information-portal/>)
- Port Economics (<https://www.porteconomics.eu/category/thema/ports-covid-19/>)
- Port Economics, Management and Policy (<https://porteconomicsmanagement.org/pemp/contents/part9/ports-and-pandemic/>)
- European Maritime Safety Agency (<https://www.emsa.europa.eu/>)
- MEDPorts Association (<https://medports.org/>)

- American Association of Port Authorities (www.aapa-ports.org)
- Centers for Disease Control and Prevention (<https://www.cdc.gov/>)
- McMaster Daily News COVID-19 (<https://covid19.mcmaster.ca/>)
- Oxford COVID-19 Evidence Service (<https://www.cebm.net/oxford-covid-19-evidence-service/>)
- World Health Organization (WHO) Coronavirus disease (COVID-19) pandemic (<https://www.who.int/emergencies/diseases/novel-coronavirus-2019>)

Manual searches were conducted in relevant reference study lists, and experts in the field were contacted. No language filter was applied, and there were no restrictions on date or language. The search strategies for each database and information source are detailed in Supplementary Material 1.

Study selection process

The study selection process used the Rayyan platform in two phases [13]. The first phase involved reading the titles and abstracts of the references found by the search strategies, and the second phase involved reading the full text of “potentially eligible” studies to confirm eligibility. Justifications for excluding studies at this stage were reported. Two independent reviewers conducted both phases, and a third reviewer resolved discrepancies in decisions to include or exclude studies.

Data extraction

Two reviewers independently extracted data from studies identified and included in this review, and discrepancies in information were resolved through consensus. The following data were collected for each study: publication year, study design, publication status (full article or abstract), study funding sources, atmospheric pollutants, and their monitoring systems, such as the Automatic Identification System (AIS), which is required on all vessels with gross tonnage, i.e., capacity volume exceeding 300 tons; and pollutant emission estimation model, capable of adjusting fuel consumption based on volume, power, speed, and the dynamic behaviour and operating mode of the vessel during a specified period. The AIS provides real-time data on the evolution of port calls (ship stops within the port) and maritime traffic (movement of vessels within and beyond the port’s 30 nautical miles range). Authors of included studies could be contacted if additional information was needed.

Data synthesis and presentation

The qualitative synthesis of included studies was presented using a narrative approach and in graphs and tables with descriptive statistics (percentage and mean/

standard deviation) related to atmospheric pollutant emission concentrations in different seaport scenarios.

RESULTS

Search Results

Search strategies retrieved 3641 references. After removing 203 duplicates, 3438 references were selected for the screening process through title and abstract analysis. After eliminating 3428 references that did not meet the inclusion criteria, 10 were identified as potentially eligible studies. The full texts were analysed, and one study was excluded as it solely assessed the economic impact of the COVID-19 pandemic on maritime transportation [14]. In the end, nine studies were included in the review [15-23]. The PRISMA flowchart of the study selection process is represented in Figure 1.

Characteristics of Included Studies

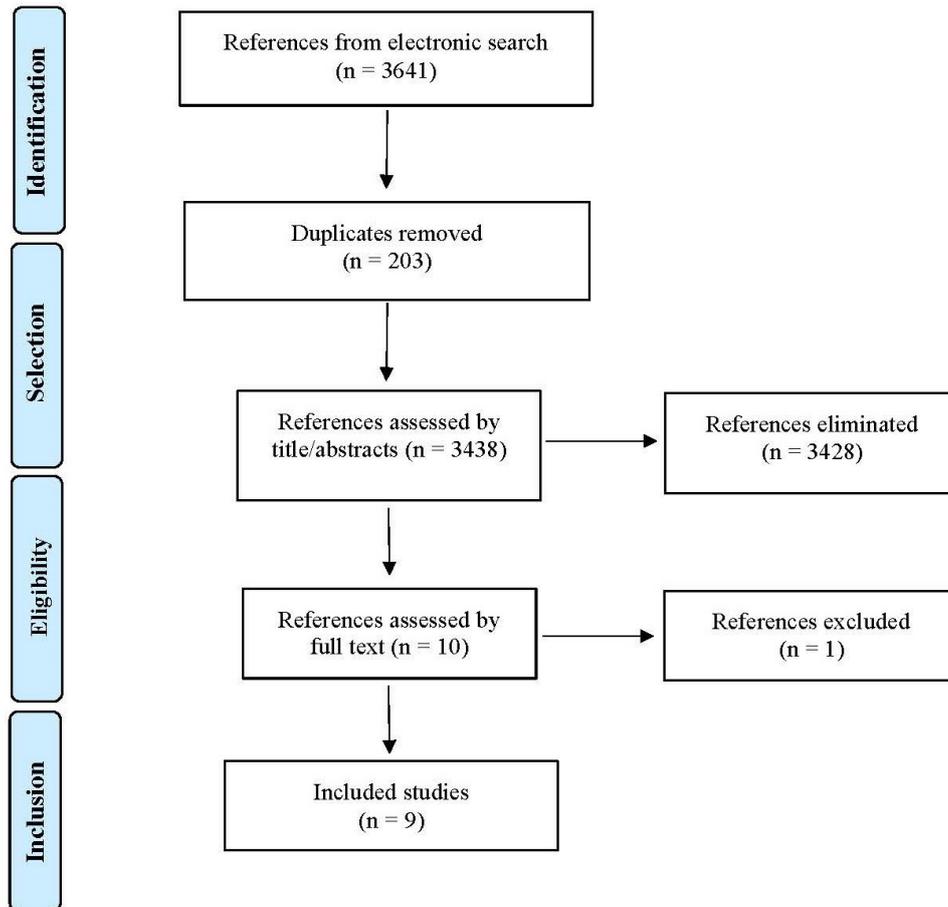
The main characteristics of the included studies are detailed in Table 1. All studies had a comparative observational design and were published as full articles. The studies were published between 2021 and 2023 and assessed, among other outcomes, the impact of sanitary restrictions imposed by the COVID-19 pandemic on the emission of atmospheric pollutants in ports from various countries, including 33,3% from China [15,17,23], 22,2% from Spain [16,21], and 44,5% from each of the following countries: Singapore [19], Italy [20], Brazil [22], and USA [18].

The monitoring systems varied among the studies; however, 75% utilised the AIS. Based on the data obtained, the studies adopted some models to estimate pollutant emissions from all vessels, such as the STEAM algorithm (Ship Traffic Emission Assessment Model) [16,21] or the MEET (Methodologies for Estimating Air Pollutant Emissions from Transport) and TRENDS (Transport and Environment Database System) models [19].

Furthermore, the studies reported monitoring and controlling climate variables and meteorological conditions, including temperature, humidity, wind speed and direction, precipitation, and thermal inversion episodes. The SENEM model (Ship’s Energy Efficiency Model), used by Durán-Grados et al. (2020) [16], predicts speed loss due to additional resistance in abnormal weather conditions (irregular waves and wind).

Most of the included studies evaluated emission factors through calculations for the following pollutants: carbon dioxide (CO₂) and sulphur dioxide (SO₂), related to vessel fuel; nitrogen oxides (NO_x), related to the engine’s type (main and auxiliary); and particulate matter (PM 2.5 and 10), among others, such as carbon monoxide (CO) and ozone (O₃).

Figure 1: PRISMA Flowchart of the study selection process



Results of included studies

Table 2 presents the findings from the nine included studies, which compared the concentration of air pollutant emissions in seaport regions before and after the COVID-19 pandemic lockdown period.

Seven studies [15,16,18,19-21,23] provided numerical data (in percentage) for the comparative analysis of pollutant gas emissions between the pre-pandemic (2019) and post-pandemic (2020/2021) periods. Regarding NO_2 , only one study [16] reported the percentage variation between the periods, showing a 63% reduction when comparing them. The same study showed an increase in O_3 emissions by 38% in 2020 compared to 2019. Ultimately, the studies by Gu & Liu (2023) [17] and He et al. (2023) [18] also identified an increase in concentrations of $\text{MP}_{2.5}$, MP_{10} , SO_2 e O_3 explained by the port congestion scenario, where the increase in vessel berthing time occurred due to the quarantine period, sanitary restrictions, and port logistics blockade

Table 1: Main characteristics of the included studies

Study, year	Location	Monitoring system / Emission estimation model	Measured air pollutant concentrations	Sampling period	Funding sources
Chen, 2021	Port of Ningbo, China	Electrochemical sensor package ('home-made')	NO ₂ , O ₃ e CO	January to March 2020 versus February to March 2019	National Key Research and Development of China and Natural Sciences Foundation of Zhejiang Province, China
Durán-Grados, 2020	Port of Algeciras and Strait of Gibraltar, Spain	AIS system / STEAM and SENEM	CO ₂ , CO, NO _x , SO _x , HC, NO ₂ , NMVOC, PM	90 days during the COVID-19 lockdown versus 'no pandemic period'	Ministry of Health, Andalusia, Spain, and other institutions
Gu, 2023	14 ports from China	AIS system / Panel Data Regression Model	PM _{2.5} , PM ₁₀ , CO, NO ₂ , SO ₂	January 2020 to July 2021 versus 'no pandemic period'	National Social Science Foundation of China
He, 2023	Port of Long Beach, USA	AIS system / Bottom-up method	CO ₂ , CO, NO _x , SO _x , PM	2019 to 2021	Nanyang Technological University, Singapore.
Ju, 2021	Port of Singapore, Singapore	AIS system / MEET and TRENDS	CO ₂	2020 versus 'no pandemic period'	No financial support reported
Mocerino, 2021	Port of Naples, Italy	AIS system/ MEET	NO _x , SO _x , PM	2020 versus 2019	No financial support reported
Mujal-Colilles, 2022	Port of Barcelona, Spain	AIS system / STEAM	CO ₂ , SO ₂ , PM, NO _x	March to June 2020 versus 2019	IAMU and ACCI'Ó, Spanish MINECO program; European Research Council
Sarra, 2022	Port of Santos, Brazil	CETESB Monitoring / CETESB-QUALAR	PM, NO _x , SO _x	2020 versus 2019	No financial support reported
Shi, 2021	Port of Shanghai, China	AIS system / Bottom-up method	CO ₂ , CO, NO _x , SO _x , HC, NO ₂ , PM	2020 versus 2019	National Natural Science Foundation of China

AIS: Automatic Identification System; CETESB: Environmental Company of the State of São Paulo; MEET: Methodologies for Estimating air Pollutant Emissions from Transport; NMVOC: non-methane volatile organic compounds; SENEM: Ship's Energy Efficiency Model; STEAM: Ship Traffic Emission Assessment Model; TRENDS: TRansport and Environment Database System. CO₂: carbon dioxide, SO₂: sulfur dioxide, NO_x: nitrogen oxides, PM: particulate matter, CO: carbon monoxide, O₃: ozone, HC: hydrocarbons.

Table 2: Results of included studies regarding pollutant emissions in Port regions

Study, year	Location	Measurement period	Results
Chen, 2021	Port of Ningbo, China	2019 versus 2020	<ul style="list-style-type: none"> • Mean NO₂ = 19.5 versus 7.2 ppb (- 63%) • Mean O₃ = 27.5 versus 7.5 ppb (+ 38%) • Mean CO = 696.6 versus 648.5 ppb (- 7%)
Durán-Grados, 2020	Port of Algeciras and Strait of Gibraltar, Spain	90 days during the COVID-19 lockdown versus 'no pandemic period'	<ul style="list-style-type: none"> • 10% to 12% reduction in all the pollutants emissions, compared to no pandemic period
Gu, 2023	14 ports, China	January 2020 to July 2021 versus 'no pandemic period'	<ul style="list-style-type: none"> • Increase concentrations of PM_{2.5}, PM₁₀, SO₂ e O₃ (percentage data not reported), compared to no pandemic period
He, 2023	Port of Long Beach, USA	2019 versus 2021	<ul style="list-style-type: none"> • Overall pollutant emissions increase from 68% to 85% due to port congestion in 2021 • Reduced CO₂ emission: 52,527 versus 46,687 million tonnes
Ju, 2021	Port of Singapore, Singapore	2020 versus 'no pandemic period'	<ul style="list-style-type: none"> • 11% reduction in CO₂, compared to no pandemic period
Mocerino, 2021	Port of Naples, Italy	2019 versus 2020	<ul style="list-style-type: none"> • NO_x 332 t versus 62 t (- 18%) • SO_x 12,6 t versus 2,4 t (- 19%) • PM 23,5 t versus 4,4 t (- 18%)
Mujal-Colilles, 2022	Port of Barcelona, Spain	2019 versus 2020	<ul style="list-style-type: none"> • NO_x - 1,3% • CO₂ - 1,8% • No significant reduction in SO and PM
Sarra, 2022	Port of Santos, Brazil	2019 versus 2020	<ul style="list-style-type: none"> • Operational activities (cargo handling) increased by 9.4% - bulk grain loading operation • Pollutant emissions in 2020 compared to 2019 (numerical data not reported): <ul style="list-style-type: none"> • Increase in PM₁₀ • Reduction in PM_{2.5} • Reduction in SO₂ • Reduction in NO_x
Shi, 2021	Porto de Shanghai, China	2019 versus 2020	<ul style="list-style-type: none"> • Ship count: 7.770 versus 4.085 (- 52,5%) • Average berthing time: 1,16h versus 4,64h (larger ships > time) • Reduction in pollutant emissions in 2020 compared to 2019: <ul style="list-style-type: none"> • 14,7% CO₂ • 16,6% CO • 10,5% HC • 13,3% NO_x • 16,3% PM_{2.5} • 16,2% PM₁₀ • 15,7% S_O2

CO₂: carbon dioxide; CO: carbon monoxide; HC: hydrocarbons; NO_x: nitrogen oxides; PM_{2.5}: particulate matter with a diameter less than 2.5 micrometers; PM₁₀: particulate matter with a diameter less than 10 micrometers; SO₂: sulfur dioxide; SO_x: sulfur oxides; AA: auxiliary engine; ME: main engine; µg/m³: micrograms per cubic meter; t: tons.

DISCUSSION

This scoping review was developed to identify and synthesise available evidence on the impacts of restrictions imposed by the COVID-19 pandemic on port activities concerning atmospheric pollutant emissions. Nine descriptive observational studies published between 2020 and 2023 were identified, analysing the emission of pollutant gases in ports of five countries and comparing periods before and after the COVID-19 pandemic. Seven studies showed a reduction of around 7% to 63% in the emission of CO₂, NO₂, CO, HC, NO_x, SO_x, HC, MP2.5, and MP10, and an increase of 38% in O₃, which is closely related to the decrease in NO₂ concentration in a scenario of volatile organic compounds. This variability in emissions is probably attributable to factors such as the varying sizes of the ports, their potential for maritime operations, and the number of vessels they accommodate. Additionally, two studies [17,18] observed increased greenhouse gas emissions explained by port congestion during COVID-19 restrictions. Conversely, one study [23] identified a reduction of over 50% in the number of ships in the port of Shanghai, likely due to large-scale suspension measures taken by cargo transport companies to mitigate pandemic-induced losses. Notably, the restrictive measures adopted to contain the pandemic led to decreased vehicle circulation, such as heavy trucks, in the port area and surroundings, likely enhancing the observed pollutant emission reduction in the studies.

The measurement systems for atmospheric pollutant emissions from different vessels consider energy demand and, therefore, the ship's dynamic behaviour and operation mode. Thus, emission models related to maritime transport within a spatial region typically consider separate emission modes for each vessel, i.e., cruising, manoeuvring, hoteling, and berthing [21].

Other factors affecting the estimates of air pollution from ships are related to engine and fuel type [18]. The total fuel consumption and emissions that ships generate depend on the vessel type and the emission mode under which the engine operates. When the ship cruises, the main auxiliary engine works while the boiler is closed. The main engine, auxiliary engine, and boiler will operate simultaneously when the ship is in manoeuvring and anchoring conditions. However, when the ship is in berthing operation, the main engine is turned off while the auxiliary and the boiler are still operating [23]. In some countries, the berthing time was longer due to strict quarantine measures, resulting in more CO₂ and SO₂ produced by the boilers of merchant ships, even though the greater volume of pollutants comes mainly from the main engines [17]. Hence, the pandemic may have altered the emission distributions of vessels due to changes in their activities.

Assigning the appropriate emission mode is crucial for a more accurate emission estimate. Although the AIS system provides navigation status information, it is

a fixed variable on the vessel. The ship's crew manually changes the AIS status and is therefore vulnerable to human errors and delays. Thus, the model used to estimate vessel emissions should consider the vessel's speed and location (within or outside port facilities) and the navigation status provided by AIS data. Another critical point is the relationship between passenger ships (cruise tourism) and pollutant emissions. These vessels operate constantly with a large cargo volume and high speeds, accounting for a significant portion of air pollution despite representing a smaller proportion of maritime traffic [21].

There is a strong correlation between the vessel's operation mode and its overall contribution to pollution. This aligns with the fact that more environmentally friendly navigation can only be achieved by reducing the average speed of vessels. The emission factor, the most critical parameter for estimating pollutant emissions, can be affected by various external factors, including engine types (main engine, auxiliary engine, boiler), fuel types (residual oil, marine distillate oil, marine gas oil), and engine status (low-speed diesel, medium-speed diesel) [23].

The increase in particulate matter emissions is related to the movement and loading of solid bulk cargo, such as soybeans and corn. One study [22] conducted at the port of Santos showed an increase in the proportion of solid bulk from 2019 to 2020, from 49% to 51.6%, with an increase in PM₁₀ averages during the same period accompanied by a reduction in PM_{2.5} concentrations. According to the authors, the higher movement of solid bulk tends to decrease the PM_{2.5}/PM₁₀ ratio due to the increased emission of PM₁₀.

Another critical factor in calculating ship emissions is considering weather and meteorological conditions that can influence the dispersion of gases and particulate matter, including the direction and speed of wind, direction and height of waves, thermal inversions, and precipitation. The study of wind behaviour is crucial as it affects pollutant dispersion conditions. Rainy weather, for example, reduces concentrations of atmospheric pollutants and increases air humidity, directly affecting sensor accuracy [19,20]. In this review, all included studies considered these measurements in their estimates of pollutant emissions.

The strengths of this scoping review involve the broad and sensitive search across various general databases and sources of information related to maritime port activities. Other aspects that provide methodological robustness involve the selection and data extraction performed in duplicate and adopting methods recommended by the Joanna Briggs Institute Manual for scoping reviews [11]. Limitations are related to the data obtained from the included studies, mainly due to possible imprecision of some monitoring systems and algorithms used for pollutant emission estimation and differences between port policies and pandemic restrictive measures among the analysed countries. Additionally, although there appears to

be a relationship between pollutant emissions, fuel consumption, and the number of vessels in the region, several other factors play an essential role in the final values of air quality, including vehicle traffic, which was reduced during the pandemic. No similar scoping reviews were found.

This scoping review provides some critical insights into understanding the effects of port activities on health and the environment, developing practical implications, and identifying preventive and mitigating strategies for atmospheric pollution in coastal cities. Fundamental measures need to be taken to improve the efficiency of port logistics and air quality in port cities. Port infrastructure and handling equipment should be modernised to enhance operational efficiency [24]. Furthermore, port authorities and stakeholders should strengthen cooperation between sectors to modify sustainability environmental policies and legislation, promote more environmentally friendly navigation, rigorously monitor companies by environmental agencies, and quantify pollutants and particulate matter through reliable real-time data systems. Implementing Green Port concepts [25] is also essential and has implications for future research. Prospective and high-quality methodological studies are needed to analyse and monitor the impact of atmospheric pollution on the health of port workers and the resident population to provide evidence to support strategies to mitigate air pollution in seaport areas.

CONCLUSION

The findings of this scoping review showed a reduction in pollutant and particulate matter emissions during the period of port activity restrictions imposed by the COVID-19 pandemic worldwide, compared to the same period in 2019. This reduction was mainly attributed to the reduced activity of vessels and vehicle circulation. These findings can provide valid scientific evidence to support the air pollution control policies in coastal cities and assist in ensuring sustainable practices, environmental regulations, and monitoring for mitigating air pollution in port regions.

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